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EFFECTS OF RESTRICTIVE SMOKING POLICIES ON INDOOR AIR QUALITY AND SICK BUILDING SYNDROME: A STUDY OF 27 AIR-CONDITIONED OFFICES

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ABSTRACT

A field experiment investigated the effects of five restrictive or prohibitive smoking policies on indoor air quality and sick building syndrome complaints in 27 air-conditioned office buildings. Indoor air quality was measured in each building. No differences among policies were found for numbers of smokers, average number of cigarettes smoked daily. No differences among policies were found for carbon monoxide, carbon dioxide, respirable particulates, relative humidity, air temperature or illumination levels. There were differences among policies in ultra-violet particulate mass and formaldehyde. There were differences in nicotine among the spatially restricted smoking policies. ETS pollutant levels were highest where smoking was restricted to rooms with local air filtration. A questionnaire survey of workers measured sick building syndrome symptoms. Symptoms were marginally less prevalent for the restrictive smoking policies than the smoking prohibited policy. Evidence that ETS is a cause of sick building syndrome complaints was not found.

INTRODUCTION

Environmental tobacco smoke (ETS) is a source of many indoor air pollutants. Various spatially restrictive or prohibitive smoking policies can be implemented to lessen the impact of ETS pollutants on indoor air quality. Studies have shown that some restrictive smoking policies have little impact on indoor air quality (1,2). These studies, however, have not examined the effects of smoking policies on the sick building syndrome (SBS). Other work suggests that passive exposure to ETS increases SBS symptoms in nonsmokers (3,4,5), although smoking activity and SBS complaints are not associated (5,6). To investigate the effect of five smoking policies (prohibition and various forms of spatial restriction) on indoor air quality and on the SBS a field experiment was conducted.

METHODS

Smoking policies and office buildings

Five smoking policies were investigated: smoking prohibited (SP); smoking restricted to rooms with local electrostatic and sorbent air filtration units (RF); smoking restricted to areas with no local air treatment (RNT); smoking restricted to rooms ventilated by a separate exhaust ventilation system (RSV); smoking restricted to enclosed offices and open plan cubicle workstations (RWS). Twenty seven air-conditioned buildings with different smoking policies were studied. The buildings had either variable air volume (VAV) or constant air volume (CAV) ventilation systems. Seventeen organizations (insurance, finance, sales and marketing, etc.) occupied these offices. Fifteen of these were private companies occupying 25 of the 27 offices, 1 was a federal agency, and 1 a municipality.

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Indoor climate survey

Buildings were surveyed in the winter/spring for two consecutive workdays (1 building was sampled for one day because a census of workers had been attained). Each day 2 office areas (sites) were sampled in the morning and 2 different sites in the afternoon. Sites were open office areas for the SP and RWS policies. For other policies sites were in nonsmoking open offices and smoking areas. In total, 117 smoking and 95 nonsmoking sites were surveyed. Sampling occurred during normal office hours on full working days following the same protocol (5). Computer controlled air sample pumps in each of two sound insulated briefcases pumped air through sorbent media and a filter to measure formaldehyde, nicotine, respirable particulates, and ultraviolet particulate mass (UVPM), a measures of particulates from ETS (6). To measure respirable particulates (<2.5 μm) air was drawn at 4 l min^{-1} for 3 hours through a single stage inertial impactor attached to one end of each briefcase. Formaldehyde (CHOH) was measured by passing air through a medium impregnated with 2,4 dinitro-phenylhydrazine at 0.25 l min^{-1} for 3 hours. Nicotine was measured by drawing air at 1 l min^{-1} through XAD-4 resin for 3 hours. Pump flow rates averaged 98% (±0.004%) of the initial settings. In each building one field blank was taken for each pollutant. Direct reading instruments were used for hourly readings of carbon monoxide (CO), carbon dioxide (CO_2), respirable suspended particulates (<3.5 μm: $RSP_{3.5}$), temperature, relative humidity, and illumination.

Questionnaire survey

Concurrent with the indoor climate survey, a self-report questionnaire was administered to approximately 30 workers in the immediate vicinity of each office air quality sample site in each building. Perceptions of ambient conditions, occupational factors, work-related health, sick building syndrome symptoms, personal details, and smoking history were collected. In 24 buildings questionnaire distribution and collection was done by the researchers on the same day, and in 3 buildings this was done by in-house staff. Of the 6,335 questionnaires distributed 4,479 were returned (average 72% return rate: minimum 58%, maximum 88%).

Statistical design and analysis

Physical environment data were analyzed as a split unit design with smoking policy as the whole unit treatment factor, time-of-day (morning or afternoon samples) and smoking designation of an area (smoking or nonsmoking) the sub-unit treatment factors, and buildings the experimental unit. The error term for testing the effect of smoking policy was the pooled variation in means among the buildings within each policy. For time-of-day and smoking area designation treatment combinations sample sites were the experimental units. Effects and interactions of time-of-day and smoking area designation were tested using the variation among site as the error term. Separate comparisons between morning and afternoon measures were made for each policy when the interaction between time-of-day and smoking policy was significant. When the effect of smoking policy was significant for a pollutant comparisons among the smoking policies were made using a set of orthogonal contrasts: RSV vs. RF (separate ventilation contrasted with air filtration in smoking rooms); RNT vs. average of RSV and RF (dilution ventilation from smoking areas contrasted with some form of air cleaning); SP vs. average of RNT, RSV, and RF (prohibiting smoking contrasted with spatial restriction of smoking); RWS vs. average of SP, RNT, RSV, and RF (dilution ventilation for dispersed sources contrasted with either spatial restrictions on smoking or source elimination). Separate analyses using only the data from the spatially restricted smoking policies (RSV, RF, RNT) were performed to test the effects and interactions of smoking area designation and smoking policy. Comparisons between smoking and nonsmoking areas were made separately for each spatially restricted smoking policy using unequal variance independent samples t-tests when the interaction was significant for a pollutant. Partial correlations among the environmental measures were calculated. CO, CO_2, and formaldehyde levels were lognormally distributed, and analyses were performed with natural log transformed data. For computational

purposes a value of 10^{-4} was added to each CO reading to avoid problems with zero readings, and zero readings for formaldehyde concentration were replaced with the detection limit of the method.

RESULTS

No differences among the policies where smoking was allowed were found for self-reports of either the number of cigarettes smoked daily: RWS (345 ± 55), RNT (186 ± 67), RSV (162 ± 67), RF (191 ± 55), or the total number of person hours spent in smoking areas in the spatially restricted policies: RSV (26.25 ± 19.55), RF (57.63 ± 15.99), RNT (18.75 ± 22.57). Although concentrations of pollutants generally were low there were significant differences among smoking policies (Table 1), and there were differences in the nonsmoking and smoking areas of the spatially restricted policies (Table 2). Gravimetric analysis of RSP was unreliable with 26 of 27 field blanks showing some discrepancy from their initial mass: 6 with negative mass, 20 with positive mass. Although derived from the gravimetric RSP samples, UVPM did not correlate with gravimetric RSP. Because of the unreliability of gravimetric RSP data no further analyses were performed.

Smoking policy affected UVPM ($F_{4,22} = 4.01$, $p = 0.0136$), and concentrations were much lower in the SP policy than in the other smoking policies (Table 1). Smoking policy interacted with site ($F_{12,150} = 6.99$, $p = 0.0001$). For the spatially restricted smoking policies UVPM levels were higher in smoking areas than in nonsmoking areas, although the difference varied among the smoking policies and was greatest for the RF policy ($F_{2,88} = 9.55$, $p = 0.0002$; Table 2). Comparisons of all nonsmoking open office areas also showed a policy effect ($F_{4,22} = 4.08$ $p = 0.0127$), and UVPM levels were different between the SP policy and the average of the RSV, RF, and RNT smoking policies ($F_{1,22} = 5.97$, $p = 0.0230$), and marginally different between the RWS smoking policy and the average of the SP, RSV, RF, and RNT smoking policies ($F_{1,22} = 4.10$, $p = 0.0552$). Partial correlation analysis showed that UVPM correlated with $RSP_{3.5}$ ($r = 0.50$, $p = 0.0001$).

Smoking policy affected $RSP_{3.5}$ ($F_{4,22} = 2.67$, $p = 0.0594$), because of the significant difference between the RSV and the RF smoking policies ($F_{1,22} = 3.95$, $p = 0.0594$). For the spatially restricted smoking policies $RSP_{3.5}$ was higher in smoking areas than nonsmoking areas, although this varied among these policies ($F_{2,88} = 8.94$, $p = 0.0003$). For only the open office areas there was no difference in $RSP_{3.5}$ among policies. Using the data from all policies $RSP_{3.5}$ correlated with UVPM ($r = 0.50$, $p = 0.0001$), CO ($r = 0.33$, $p = 0.0001$), and formaldehyde ($r = 0.23$, $p = 0.0038$).

Nicotine concentrations were significantly different among the spatially restrictive smoking policies, whether the RSV policy was included ($F_{2,12} = 8.22$, $p = 0.0056$) or excluded ($F_{1,9} = 12.90$, $p = 0.0058$): the RF smoking policy had the highest concentration of nicotine (Table 1). Nicotine concentrations were higher in smoking areas than in nonsmoking areas for both the RF and RNT smoking policies. In the smoking areas for the RF smoking policy nicotine levels was more than fourfold those for the RNT smoking policy, whereas in nonsmoking areas nicotine levels were very low for both smoking policies (Table 2). Partial correlations for the data from the spatially restricted policies showed that UVPM correlated with nicotine ($r = 0.32$, $p = 0.0057$).

Except for the RNT smoking policy where formaldehyde averaged 0.05 ppm, concentrations generally were at or below 0.02 ppm. Smoking policy did not affect formaldehyde, although there was a smoking policy with site interaction ($F_{12,150} = 3.34$, $p = 0.0003$). Formaldehyde levels were slightly higher in smoking areas than nonsmoking areas in the spatially restricted smoking policies (Table 2), but there were no differences among the sites for the SP and RWS policies (Table 1). There was a marginal effect of smoking policy on formaldehyde for the spatially restricted smoking policies (RSV, RF and RNT: $F_{2,12} = 3.75$, $p = 0.0543$), because of the difference between the RNT and the average of the RSV and RF policies ($F_{1,12} = 7.44$, $p = 0.0184$). Smoking policy interacted with smoking area designation ($F_{2,44} = 3.56$, $p = 0.0326$): there was no difference in formaldehyde between smoking and nonsmoking areas for the RSV policy; formaldehyde levels in smoking areas were double those in the nonsmoking areas for the RF policy; and the RNT smoking policy had the

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highest formaldehyde levels in both nonsmoking and smoking areas (Table 2). For only the open office areas, there was a significant difference for formaldehyde between the RNT and the average of the RSV and RF policies ($F_{1,22}$ = 5.23, p = 0.0321), again because formaldehyde levels were highest for the RNT policy. Partial correlation analysis showed that formaldehyde correlated with CO (r = 0.28, p = 0.0005) and with CO_2 (r = 0.26, p = 0.0013).

CO levels were very low, and they were not affected by smoking policy, although there was an interaction of smoking policy with site ($F_{12,150}$ = 1.96, p = 0.0320). For the spatially restricted policies CO levels were higher in smoking areas than in nonsmoking areas ($F_{1,88}$ = 26.40, p = 0.0001; Table 2). Partial correlations showed that CO and CO_2 were positively correlated (r = 0.26, p = 0.0011). Smoking policy did not affect CO_2, temperature, relative humidity or illumination, but analysis of only the spatially restricted smoking policies showed higher levels of CO_2 ($F_{1,88}$ = 5.89, p = 0.0173) and lower levels of illumination ($F_{1,88}$ = 4.02, p = 0.0481) in the smoking areas (Table 2). Partial correlations showed that RH was positively correlated with formaldehyde (r = 0.23, p = 0.0050) and CO_2 (r = 0.33, p = 0.0001), but negatively correlated with temperature (r = -0.17, p = 0.0341).

The effects of prohibiting smoking versus allowing smoking were tested by comparing the SP and RWS smoking policies (in SP buildings there was no smoking and in RWS buildings smoking could occur at any desk). No significant differences between the SP and RWS smoking policies were found in levels of CO, CO_2, metered RSP, formaldehyde, illumination, temperature or RH, but UVPM levels were higher for the RWS smoking policy ($F_{1,22}$ = 38.75, p = 0.0001: Table 1).

Work-related SBS symptoms were defined as those experienced at least once in the month prior to the survey and which were alleviated when away from the building. The adjusted average number of SBS symptoms per worker in each building, termed the building sickness score (BSS), was calculated. There was only a marginal effect of smoking policy on BSS ($F_{4,22}$ = 2.62, p = 0.0627), and the BSS was slightly higher for the SP policy (4.71 ± 0.41) than for other policies (RSV = 3.83 ± 0.51; RF = 3.04 ± 0.41; RNT = 3.46 ± 0.45; RWS = 3.16 ± 0.41). There was no significant effect of smoking status on the BSS. There were no significant associations between passive exposure to ETS at work, at home, at other locations, or total passive smoking exposure and the number of SBS symptoms per worker. Logistic regression was used to test the association between nicotine, used an indicator of ETS exposure, and reports of symptoms among non-smokers working in the RWS buildings where smoking was only restricted to the workstation. Separate intercepts were needed for each building (p = 0.0001) in these analyses. Results showed that reports of stuffy, congested nose (slope = 0.06±0.02, p = 0.004: 191 of 827 non-smokers reported this symptom), and hoarseness (slope = 0.06±0.03, p = 0.043: 59 of 829 non-smokers reported this symptom) were associated with increasing concentrations of nicotine. No other SBS symptoms were significantly associated with nicotine levels.

DISCUSSION

Although there were consistent differences in indoor air quality among the 5 smoking policies which were related to ETS the size of these differences was small. Overall, the pollutant concentrations measured for the different policies agrees well with previous work (1,2). UVPM wa correlated with nicotine which agrees with previous work suggesting that it is a measure of particulates from ETS (6). UVPM was lower for the SP policy than for other smoking policies, but UVPM did not correlate with the BSS. Interestingly, the highest concentrations of pollutants from ETS (nicotine and UVPM) were found in the smoking areas served by local air filters (electrostatic filters). These devices may have acted as pollutant sinks or may have been poorly maintained or malfunctioning. Further research is needed to clarify this result.

ETS exposure for nonsmokers working in RWS buildings was associated with complaints of stuffy, congested nose and hoarseness. ETS exposure of nonsmokers in offices in buildings where smoking occurred was estimated by assuming that a fully burned cigarette releases 820 μg of nicotine into the air, that the normal breathing volume of the office worker is 0.516 m^3 hr^{-1}, and that the worker

works an 8 hour day for 250 days per year. From the nicotine levels shown in tables 1 and 2, a nonsmoking office worker who works in the open office may be exposed to the nicotine content of about 3 cigarettes per year for the RWS smoking policy, and if the worker does not spend time in a designated smoking area, about 5 cigarettes per year for the RNT smoking policy, about 9 cigarettes per year for the RSV smoking policy, and about 26 cigarettes per year for the RF smoking policy. Whether the estimated exposures in terms of equivalent cigarettes smoked per year are of significance from a health perspective is beyond the scope of this paper.

For the spatially restricted smoking policies formaldehyde was higher in smoking areas than in nonsmoking areas, but there was no effect of smoking policy on formaldehyde when only open offices were compared. This suggests that formaldehyde in open offices may be from various sources, such as that which is offgassed by the building materials and furnishings. Formaldehyde was not correlated with the BSS. Thermal conditions among the buildings were comparable and neither temperature nor RH was significantly associated with the BSS. CO_2 did not correlate with the BSS, confirming previous findings (6,8). There was a marginally significant effect of smoking policy on the BSS, but this was the opposite to that expected: the BSS was slightly higher for the SP policy than for other restrictive smoking policies. This result does not mean that prohibiting smoking causes the sick building syndrome, but it suggests that pollutants other than ETS affect sick building syndrome. This finding agrees with work reporting that smoking activity does not correlate with sick building syndrome symptoms (5,6), but conflicts with other work reporting an association between passive smoking and the sick building syndrome (3,4,5). This discrepancy in results may arise because sick building syndrome symptoms were defined here as those occurring at least once during the past monthe which recover when away from work, whereas other studies have used different definitions: during the past 7 days equally at work or home plus mostly at work (5), or daily or weekly in the past 12 months (3). Other differences include smoke exposure being confounded with type of office accommodation (3). The results show that for the amount of smoking activity which we observed various spatially restrictive smoking policies can be implemented without jeopardizing indoor air quality for nonsmokers in open offices. Also, they show that the differences in indoor air quality which were found do not account for the variations in SBS among the offices studied.

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Table 1. Effects of smoking policy on indoor environment conditions.

	SMOKING POLICY				
	Smoking Prohibited [SP]	Restricted Sep. Ventil. [RSV]	Restricted Filtration [RF]	Restricted No Treat. [RNT]	Restricted Workstation [RWS]
CO (ppm)*	0.1 (0.00-0.5)	0.7 (0.1-5.2)	0.4 (0.1-2.1)	0.6 (0.1-3.3)	0.1 (0.0-0.5)
CO_2 (ppm)*	561 (478-657)	600 (494-729)	674 (575-791)	634 (533-755)	573 (488-671)
CHOH (ppm)*	0.01 (0.008-0.028)	0.02 (0.009-0.046)	0.02 (0.013-0.047)	0.05 (0.025-0.103)	0.01 (0.008-0.028)
$RSP_{3.5}$ ($\mu g\ m^{-3}$)	14.8 ± 14.0	28.9 ± 17.17	2.7 ± 14.02	5.3 ± 15.32	2.6 ± 14.0
UVPM ($\mu g\ m^{-3}$)	0.2 ± 22.9	44.1 ± 28.1	114.9 ± 22.9	19.8 ± 25.1	10.2 ± 22.9
Nicotine ($\mu g\ m^{-3}$)	ND	6.9 ± 3.0**	20.8 ± 2.4	3.8 ± 2.6	2.4 ± 2.4
Temp. (°C)	23.9 ± 0.4	24.3 ± 0.5	23.9 ± 0.4	23.7 ± 0.4	23.6 ± 0.4
RH (%)	29.7 ± 3.5	35.1 ± 4.3	33.4 ± 3.5	28.3 ± 3.9	35.9 ± 3.5
Illum. (lux)	472.4 ± 62.4	513.3 ± 75.3	507.9 ± 62.4	586.4 ± 67.8	564.9 ± 62.4

Table 2. Differences in indoor environment conditions for nonsmoking and smoking areas of spatially restricted smoking policies.

	SMOKING POLICY					
	RSV Nonsmoking	RSV Smoking	RF Nonsmoking	RF Smoking	RNT Nonsmoking	RNT Smoking
CO (ppm)*	0.3 (0.2-0.7)	1.5 (0.7-3.4)	0.2 (0.1-0.3)	1.2 (0.7-2.1)	0.4 (0.2-0.8)	1.0 (0.4-2.2)
CO2 (ppm)*	573 (523-627)	635 (571-707)	673 (626-732)	676 (550-644)	597 (550- 647)	698 (624-781)
CHOH (ppm)*	0.02 (0.013-0.024)	0.02 (0.017-0.034)	0.02 (0.014-0.022)	0.04 (0.030-0.049)	0.05 (0.038-0.063)	0.06 (0.039-0.079)
$RSP_{3.5}$ ($\mu g\ m^{-3}$)	11.9 ± 10.1	53.7 ± 12.0	30.2 ± 8.0	126.1 ± 8.8	19.3 ± 9.0	35.6 ± 12.5
UVPM ($\mu g\ m^{-3}$)	3.2 ± 23.1	109.1 ± 27.3	14.5 ± 18.3	236.6 ± 20.0	9.3 ± 20.5	35.6 ± 28.6
Nicotine ($\mu g\ m^{-3}$)	ND	8.2 ± 5.1**	0.9 ± 3.3	44.2 ± 3.6	0.3 ± 3.8	10.3 ± 5.2
Temp. (°C)	24.4 ± 0.2	24.4 ± 0.2	24.0 ± 0.2	23.8 ± 0.2	23.7 ± 0.2	23.8 ± 0.2
RH (%)	34.6 ± 1.3	35.4 ± 1.5	33.2 ± 1.0	33.6 ± 1.1	28.2 ± 1.2	28.7 ± 1.6
Illum. (lux)	544.5 ± 48.4	488.5 ± 57.0	515.4 ± 38.7	503.6 ± 42.0	648.8 ± 43.0	474.5 ± 60.3

* means backtransformed from natural logarithm scale
** nicotine only measured in separately ventilated smoking areas
() backtransformed 95% confidence limits

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